8.0 DOSE CALCULATIONS

For operating DOE-controlled facilities, DOE 5400.1 and DOE 5400.5 describe the annual reporting requirements for releases of radioactive materials to the environment. In addition to the summary of total curies (by radionuclide) in airborne and liquid effluents released to the offsite environment, these Orders require the reporting of estimates of the effective doses to the population and to the maximally exposed individual in the vicinity of DOE-controlled facilities. The offsite dose estimates require detailed knowledge (or estimates) of the concentrations of radionuclides in the facility effluents and emissions and in various environmental media resulting from site operations. Samples of air, soil, water, and vegetation, and direct readings of external radiation can be used to determine these offsite concentrations. However, in most cases these concentrations are very low and challenge the sensitivity of the analytical techniques used. As a result, estimates of environmental concentration and human exposure and the resulting estimated radiation dose are frequently made using mathematical models that represent various environmental pathways. For situations where available environmental data are sufficiently accurate to determine radionuclide concentrations, their use in the dose assessment process is encouraged. For the purposes of this Order, the following basic definitions are used:

- **Model** - A mathematical formulation or description of a physical, ecological, or biological system, which includes specific numeric values or parameters

- **Computer Program** - The logical computer language statements in an executable form on a digital computer that represents the model (mathematical formulation) and appropriate data.

8.1 PERFORMANCE STANDARDS FOR PUBLIC DOSE CALCULATIONS

8.1.1 Required Standards

The requirements to be followed when calculating public radiation dose are listed in the summary. DOE programs for surface- and ground-water monitoring, reporting, and modeling are under consideration by the DOE Office of Environmental Guidance and Compliance; thus, few details on these subjects are provided in this guide. These requirements will be broad enough to define conditions for radionuclides and associated chemicals that could enter surface or ground waters. Except where mandated otherwise (e.g., compliance with 40 CFR Part 61), the assessment models selected for all environmental dose assessments *should** appropriately characterize the physical and environmental situation encountered. The information used in dose assessments *should** be as accurate and realistic as possible. Complete documentation of assessments of the radiation dose resulting from the operation of DOE-controlled facilities *should** be provided in a manner that supports the annual site environmental

monitoring report, Environmental Monitoring Plan, or other application, and show the 1) models used, 2) computer programs used, and 3) input data and data source assumptions made.

8.1.2 Documentation and Conformance with Other Requirements

Default values used in model applications *should** be documented and evaluated to determine appropriateness to the specific modeling situation. When performing human foodchain assessments, a complete set of human exposure pathways *should** be considered, consistent with current methods (IAEA 1982; Moore et al. 1979; NCRP Report No. 76; NUREG/CR-3332). Surface- and ground-water modeling *should** be conducted as necessary to conform with the applicable requirements of the State government and the regional office of the EPA.

8.2 MAJOR CONSIDERATIONS

The basic considerations in performing an analysis of dose to the general public for the annual releases of radioactive materials from DOE facilities are shown in Figure 8-1. Source-term estimates (box 1 in Figure 8-1) are obtained from the effluent monitoring programs established for each site, as described in Chapters 2 and 3 of this Order. Models (boxes labeled 2 in Figure 8-1) are then applied for atmospheric, surface-water, and ground-water transport. Environmental pathway analysis models (box 3 in Figure 8-1) are then used to account for bioaccumulation in food products and the annual usage or uptake of materials by members of the public. The dose-rate factors (boxes labeled 4 in Figure 8-1) to be used are the standard factors listed in the EPA publication Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion

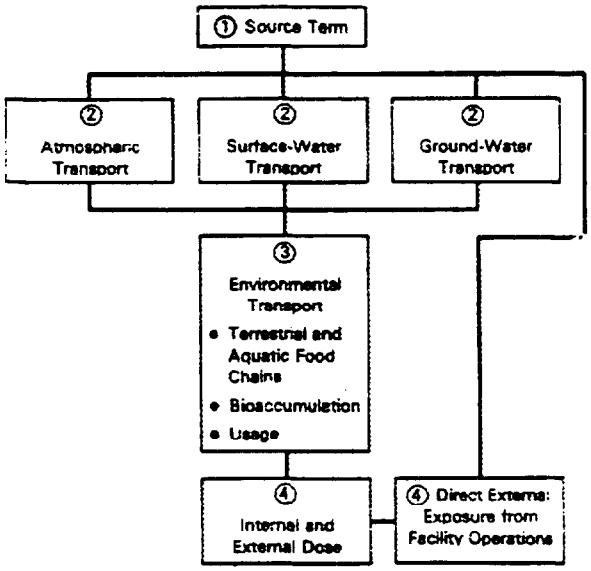

FIGURE 8-1. Major Steps in Performing Public Radiation Dose Calculations

(EPA-520/1-88-020) and in the DOE documents entitled Internal Dose Conversion Factors for Calculation of Dose to the Public (DOE/EH-0071) and External Dose-Rate Conversion Factors for Calculation of Dose to the Public (DOE/EH-0070).

8.2.1 Considerations for Selection

In applying models and computer programs for estimating public radiation doses, the following three critical assumptions *should* be evaluated for each application (Hoffman and Baes 1979): 1) the data available for the input parameters represent the true populations of the parameters (i.e., the data represent reality), 2) the model parameters are statistically independent (i.e., no coupled parameters), and 3) the structure of the model is an approximation of reality (i.e., the model fits the situation encountered). Although these three conditions can never be completely met, reasonable efforts *should* be made to evaluate these assumptions in light of the models and data sets selected for site-specific applications.

8.2.2 Misuses of Models

The three most common misuses of these types of models are "overkill," inappropriate prediction, and misinterpretation (NCRP Report No. 76). "Overkill" occurs when the level of available data or the use of the results do not support the sophistication of the model selected. The National Council on Radiation Protection and Measurements (NCRP) was responding to "overkill" in models used for radiological assessments when they made the following comment (NCRP Report No. 76, p. 239):

> In recent years, the trend has been toward more complex models; however, the increased complexity has not necessarily improved the accuracy of estimates of dose and, in certain cases, has had the opposite effect.

Inappropriate prediction occurs when sophisticated models and detailed analyses are used too early in the assessment process. Initial assessments *should* be conducted with very simple models; more detailed models and more detailed assessments *should* be made as data and knowledge of the system being modeled improve.

Modeling results can be easily misinterpreted when inappropriate boundary conditions or assumptions have been used. The results of any modeling application *should* be viewed as estimates of reality, and not reality itself. In many cases, seemingly minor changes in assumptions or input can cause drastic changes in the results obtained (NCRP Report No. 76).

8.3 TRANSPORT MODELS

Radioactive materials released in the liquid effluents or airborne emissions from an operating DOE-controlled site or facility and transported through the environment might result in radiation exposures to members of the public. As shown in Figure 8-1, the three major types of transport considered in evaluating the effects of radionuclides released to the environment are

1) atmospheric transport, 2) surface-water transport, and 3) ground-water transport. To estimate the concentrations of radioactive materials in the air or water at locations offsite, a number of mathematical models and computer programs are available. Examples of the methods for documenting computer programs are presented by the American National Standards Institute (ANSI N413) and the Federal Information Processing Standard FIPS Pub. 38. The correct operation of computer programs selected for performing the transport calculations for all environmental dose assessments *should* be verified on a specific computer system. This verification can be done by comparing the program results for sample problems against either documented sample problem results or against hand calculations. Complete validation of all models (testing the computer program against actual field or laboratory data) is not feasible because of the size of some data sets and the inability to fully characterize most sites. Thus, limited comparisons against field or laboratory data are typically conducted during development of the computer program. As a result of these limited tests, modifications are often made to key parameter values to make the results compare more closely to measured conditions. This comparison process is called "model calibration" and is often used when site-specific model applications are desired. In many situations, site-specific data are not available, so default parameters or data sets are typically used in the transport calculations. These default values are often obtained from generic data sets and are designed to give conservative dose overestimates.

8.3.1 Atmospheric Transport and Dispersion Models

Atmospheric dispersion models are typically applied to model the transport of airborne releases of radioactive materials. The modeling results obtained are useful to 1) assess the potential consequences of releases from proposed facilities or facility modifications, 2) assess the consequences of actual routine releases, 3) demonstrate compliance with regulations and standards, and 4) assess the consequences of actual accidental releases.

Atmospheric dispersion models and meteorological data that are most useful in making these calculations will vary in sophistication and complexity (depending upon the magnitude of the release) from relatively simple computations to extensive computations that require computers. Use of simple compliance assessment models, based on conservative assumptions and little or no meteorological data, could be sufficient for some DOE facilities. As the potential magnitude of the release increases, more realistic models become necessary to assess the potential consequences.

Selection of an adequate atmospheric dispersion model for estimating public radiation doses resulting from atmospheric releases of radioactive materials at DOE sites first requires the determination of site-specific data for a variety of parameters. These data are typically collected through a meteorological measurement program, as described in Chapter 5. The types of parameters required include horizontal and vertical diffusion parameters, wind data, plume-rise parameters, and plume deposition and depletion factors (Randerson 1984c). For the purposes of routine dose assessment, it is assumed that 1) the atmospheric releases occur over a long period of time (i.e., they are chronic releases from routine facility operation and not short-term accidental

releases), 2) the purpose of estimating ground-level concentrations is to conduct annual public dose assessments, and 3) local terrain is not a complicating factor.

On December 15, 1989, the EPA published the revised "National Emission Standards for Hazardous Air Pollutants; Standards for Radionuclides" (40 CFR Part 61, Subpart H). This regulation applies to operating DOE nuclear facilities and sites. For DOE facilities, subpart H establishes radiation dose limits for the maximally exposed member of the public from all airborne emissions and pathways. The dose to the maximally exposed member of the public must be calculated using only the AIRDOS-EPA (Moore et al. 1979) and RADRISK (Dunning et al. 1980) computer programs (currently referred to as CAP-88), or other methods specifically approved by EPA as specified in 40 CFR Part 61. Other approved methods could include the use of environmental data in the evaluation.

In their Annual Site Environmental Reports, most DOE sites have historically provided radiation doses determined by the ratio to the DOE concentration guides or by using the total emissions to model the downwind transport and subsequent exposure through environmental pathways (Kennedy and Mueller 1982). To apply for continued use of site-specific methods and models for demonstrating compliance with 40 CFR Part 61, it is necessary for DOE and its contractors to show that the atmospheric transport and dispersion models used are "equivalent" to those in AIRDOS-EPA (CAP-88) or AIRDOS-PC (version 3.0) and that the environmental transport assumptions and dose conversion factors used are equivalent to or more conservative than those used in RADRISK or that, for some site-specific reason, AIRDOS and RADRISK are not applicable to the site. Atmospheric transport modeling *should* be conducted by a professional meteorologist or equivalent with modeling experience.

8.3.2 Surface- and Ground-Water Transport Models

The annual reporting requirements for DOE-controlled facilities include information on liquid releases (DOE 5400.1). The information reported is required to include statements concerning the quantity and type of radioactive materials discharged to receiving streams or aquifers and assessments of the potential radiation dose to the public that could have resulted from these discharges during the previous calendar year. Decisions about which model or models will be used in performing a specific assessment depend on the local site conditions, the receiving stream or aquifer characteristics, the duration of the release, the potential exposure pathways, the magnitude of the potential doses that result, and other factors. The variety of modeling approaches indicates that there is much uncertainty in modeling surface- and ground-water systems, and that many unanswered questions about radionuclide transport through surface- and ground-water systems remain. Additional questions about surface- and ground-water dispersion models have arisen from the need to identify the parameters that can be measured in the field that correspond to the parameters used in the models. Surface- and ground-water modeling in support of the operation of DOE facilities *should* be conducted by a professional geohydrologist or equivalent with modeling experience. This modeling *should* be done using site-specific data and taking into consideration the important characteristics of the site.

8.4 ENVIRONMENTAL PATHWAY MODELS

Emission or effluent data and data from estimates of atmospheric, surface-water, and ground-water radionuclide concentrations are used as input to environmental pathway analysis models. These models predict the environmental transport of radionuclides in the human environment. For most facilities and environmental media, the concentrations in the environment are too low to adequately measure; thus, modeling is used to predict values. A summary of the major environmental radiation exposure and transport pathways relevant to operating DOE facilities that *should* be considered is given in Figure 8-2. In this figure, processes or steps that are typically modeled are shown in boxes. Processes or steps that can be either modeled or obtained from monitoring data are shown in hexagons. A more complete listing of the potential individual pathways that *should* be considered in environmental pathway modeling is given in Table 8-1. Pathway analysis and transport models *should* be compared or calibrated with field data when such information is available. To assess the operational releases from nuclear facilities, NRC Regulatory Guide 1.109 (NRC 1977) provides terrestrial foodchain transport models that address most of the steps shown in Figure 8-2. These models were adapted from the HERMES model (Soldat and Harr 1971) and are representative of the types of models that are frequently used (Hoffman and Baes 1979; Hoffman et al. 1977; IAEA 1982; Moore et al. 1979; NCRP Report No. 76; NUREG/CR-3332, Whelan et al. 1987; Napier et al. 1988; Gilbert et al. 1989; Droppo et al. 1989).

8.5 INTERNAL DOSIMETRY MODELS

DOE 5400.5 requires the use of the standard dose conversion factors published by DOE for both internal and external radiation (DOE/EH-0070 and DOE/EH-0071) or those published in EPA publication EPA-520/1-88-020, Federal Guidance Report No. 11. These methods are based on the most recent recommendations of the ICRP (ICRP Publications 23 and 30). This requirement does not apply to the use of the EPA CAP-88 and AIRDOS-PC codes (EPA-520/6-89-035; EPA 1990).

8.6 DOSE TO NATIVE AQUATIC ORGANISMS

DOE 5400.5, Chapter II, paragraph 2a(5) contains an interim absorbed dose limit of 1 rad/day to protect native aquatic organisms, other than plants, from exposure to radioactive material in liquid wastes discharged to natural waterways. So that DOE-controlled sites are in compliance with this limit, an assessment of the potential dose to native aquatic organisms *should* be conducted and included as part of the site Environmental Monitoring Plan. Dose evaluations for aquatic biota require the identification of important pathways and species for a given environment. Because of the diversity of organisms and the variety of pathways and radionuclides that must be considered, it is not possible to develop a single generalized model that can be assumed to cover all possible conditions. Instead, a site-specific assessment, using the best available data for a given facility and environment, *should* be conducted.

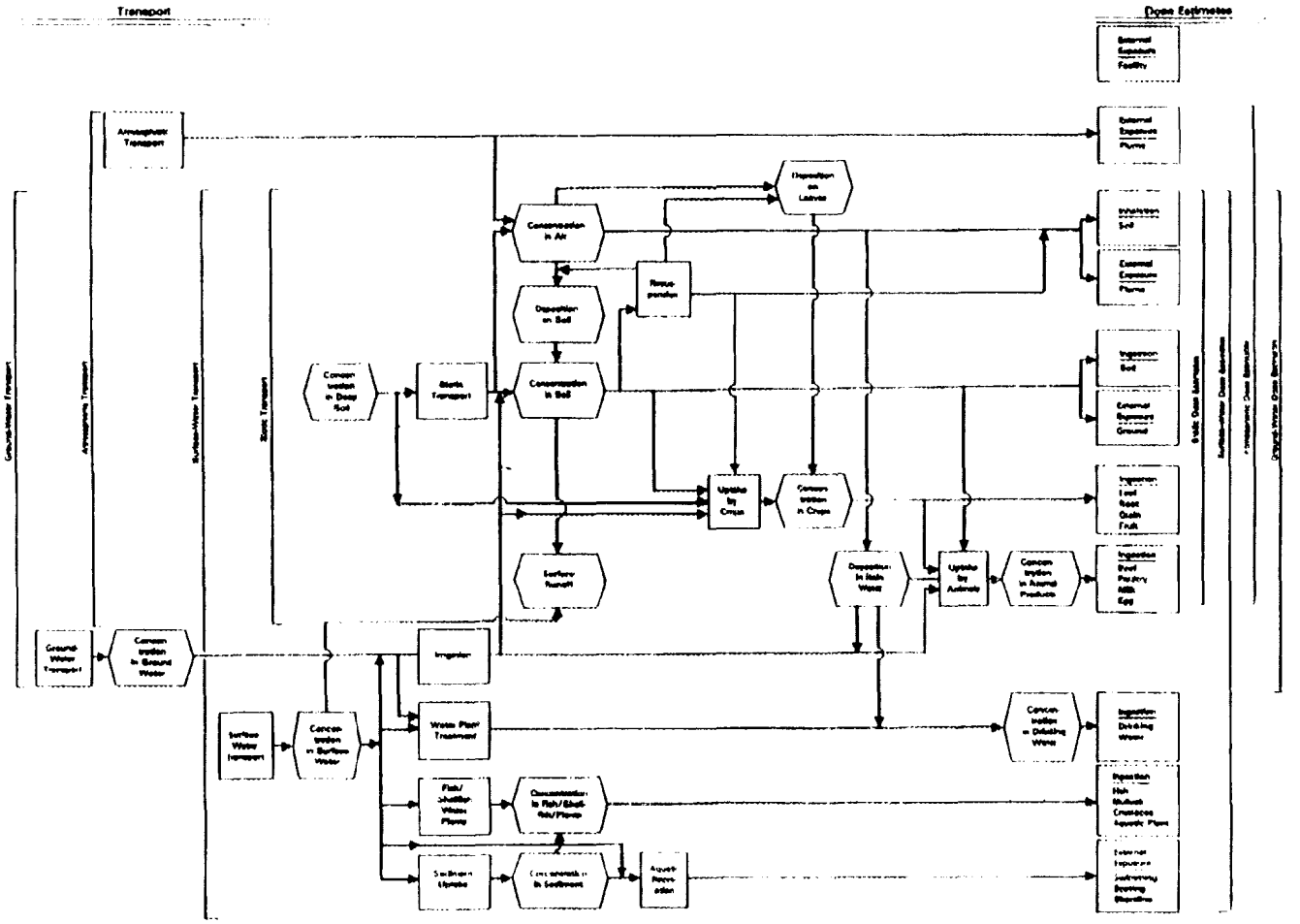

FIGURE 8-2. Potential Steps in Performing Public Radiation Dose Calculations for Various Environmental Pathways

TABLE 8-1. Potential Pathways to Be Considered in Environmental Pathway Analyses

Exposure Category	Environmental Pathway
External	Direct Facility Radiation Submersion in an Airborne Plume Contaminated Land Aquatic Recreation (Swimming/Shoreline/Boating)
Inhalation	Submersion in an Airborne Plume Resuspended Materials
Ingestion of Terrestrial Foods	Vegetables: Potatoes Other Root Vegetables Leafy Vegetables Other Vegetables Fruits Cereal Grains Animal Products: Liquid Milk Cheese Meat and Meat Products (Beef, Pork, Poultry) Eggs
Ingestion of Aquatic Foods	Fish Seafood (Shellfish)
Ingestion of Soil	Grazing Animals Humans (Children)
Ingestion of Drinking Water	Surface Water (Raw or Treated) Well Water (Raw or Treated) Rain Water

To assist in the dose calculations, a variety of computerized models may be used, including CRITR (Soldat et al. 1974) and EXREM III and BIORAD (Trubey and Kaye 1973). The National Council on Radiation Protection and Measurements has been asked by DOE/EH to make a further recommendation concerning the interim dose limit to aquatic biota and to provide additional guidance on monitoring and dose modeling.

8.7 QUALITY ASSURANCE

The general quality assurance program provisions of Chapter 10 *should** be followed as they apply to performing calculations that assess dose impacts. Specific quality assurance activity requirements for performing dose calculations for a facility/site are to be contained in the Quality Assurance Plan associated with the facility.